Electric fields	**Electric potential and potential energy**

Learning objectives	**MUST (C)**	Define electric potential and electric potential energy
	SHOULD (B)	Apply the equation for electric potential and electric potential energy
	COULD (A/A*)	Derive and apply the equation for capacitance of an isolated sphere

STARTER: Give your answer, and write a full explanation.

EXTENSION: What other quantity(ies) could be calculated with no more information? What further information would you need for the others?

An electron is in an electric field of strength 5×10^4 V m^{-1}. The field is the only influence on the electron.

The mass and charge of an electron are known.

Which quantity can be calculated without any more information?

A the force on the electron

B the momentum of the electron

C the kinetic energy of the electron

D the speed of the electron

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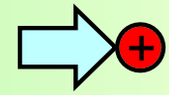
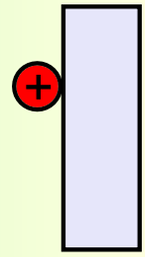
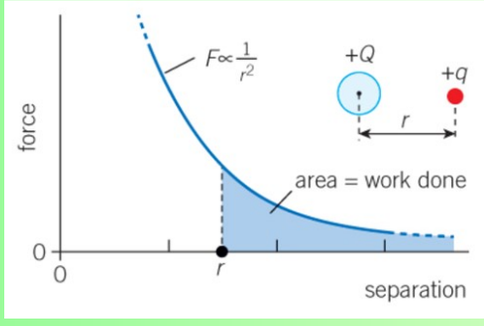
These positive charges repel each other. If you want to bring the left-hand one closer to the right-hand one, you need to do work upon the charge. The energy transferred is stored as electric potential energy.







The graph shows the force-distance relationship between two positive particles of charges *q* and Q. The area under the graph, shown as shaded, is **the total work done to bring the particles from infinity to separation *r***. This is the same as the **electric potential energy E** (careful - E denotes both electric field strength and electric potential energy).

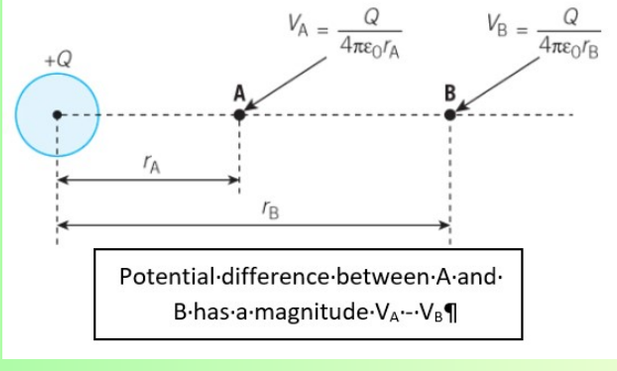
Equation for electric potential energy:

$$E = \frac{Qq}{4\pi\varepsilon_0 r}$$

Note: A negative and positive charge will have a **negative** electric potential energy, as they are attracted and so work must be done to move them apart. Like charges will have **positive** electric potential energy.

The **electric potential, V**, at a point is the work done *per unit charge* in bringing a positive charge from infinity to that point. For a test charge, *q:*

$$V = \frac{E}{q} \qquad V = \frac{Qq}{4\pi\varepsilon_0 rq} \qquad V = \frac{Q}{4\pi\varepsilon_0 r}$$



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Electric fields	**Electric potential and potential energy**
MUST (C)	Define electric potential and electric potential energy

Mini-plenary

An electron and a proton are 1.0×10^{-10} m apart. In the absence of any other charges, what is the electric potential energy of the electron?

A $+2.3 \times 10^{-18}$J
B -2.3×10^{-18}J
C $+2.3 \times 10^{-8}$J
D -2.3×10^{-8}J

$e = 1.6 \times 10^{-19}$ C

$\varepsilon_0 = 8.85 \times 10^{-12}$ Fm^{-1}

B

Extension: Convert your answer to electronvolts

$-2.3 \times 10^{-18} / 1.6 \times 10^{-19} = -14.375$ eV

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Electric fields	**Electric potential and potential energy**
SHOULD (B)	Apply the equation for electric potential and electric potential energy

Answer questions 1, 2 and 3 for section 22.5.

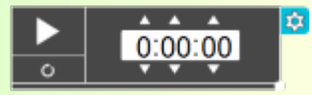
1 $E \propto \frac{1}{r}$, therefore as r is doubled E will halve. [1]

$E = 2 \times 10^{-19}$ J [1]

2 10 J of work is done in bringing a unit charge from infinity to the surface of the sphere. [1]

3 $V = \frac{Q}{4\pi\varepsilon_0 r} = \frac{1.6 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times 8.8 \times 10^{-16}}$ [1]

$V = 1.64 \times 10^{6}$ V $\approx 1.6 \times 10^{6}$ V [1]



Extension: The electric potential at a distance *r* from a positive point charge is 45V. The potential increases to 50V when the distance from the charge decreases by 1.5 m. What is *r*?

Solution:

Electric fields	**Electric potential and potential energy**
COULD (A/A*)	Derive and apply the equation for capacitance of an isolated sphere

The electric potential on the surface of a charged sphere can be found using: $V = \frac{Q}{4\pi\varepsilon_0 r}$

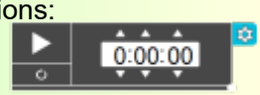
in which Q is the charge stored in the sphere and *r* is its radius.

Since the sphere is storing charge, it is acting as a capacitor.

Deriving the equation for capacitance of a sphere with radius R

You should be able to derive the equation using these two equations:

$C = \frac{Q}{V}$ $V = \frac{Q}{4\pi\varepsilon_0 R}$



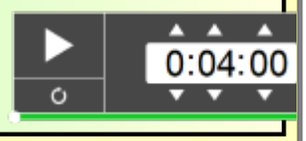
1. Rearrange the potential equation for Q: $Q = 4\pi\varepsilon_0 RV$

2. Use this value for Q in C = Q/V: $C = \frac{Q}{V} = \frac{4\pi\varepsilon_0 RV}{V}$

3. Cancel V: $C = 4\pi\varepsilon_0 R$

Now try summary questions 5 and 6 for section 22.5.

Extension: Go on to the practice questions



5 a $C = 4\pi\varepsilon_0 r = 4\pi \times 8.85 \times 10^{-12} \times 0.02$

$C = 2.23 \times 10^{-12}\ \text{F} \approx 2.2 \times 10^{-12}\ \text{F}$

b $Q = VC = 6000 \times 2.23 \times 10^{-12}$

$Q = 1.34 \times 10^{-8}\ \text{C (magnitude only)}$

$\text{number of electrons} = \frac{1.34 \times 10^{-8}}{1.6 \times 10^{-19}}$

$= 8.4 \times 10^{10}\ \text{electrons}$

6 $\text{energy} = 1.0 \times 10^{6} \times 1.6 \times 10^{-19}$

$1.0 \times 10^{6} \times 1.6 \times 10^{-19} = \frac{Qq}{4\pi\varepsilon_0 r}$

$= \frac{\left(1.6 \times 10^{-19}\right)^2}{4\pi \times 8.85 \times 10^{-12} \times r}$

$r = 1.44 \times 10^{-15}\ \text{m} \approx 1.4 \times 10^{-15}\ \text{m}$

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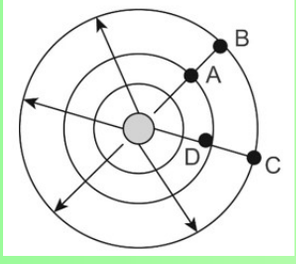
PLENARY: Equipotential lines are lines showing regions with the same potential. The charge in the diagram shows field lines and equipotential lines around an isolated positive charge. Complete the sentences with words or phrases.



When the charge is moved from either A to B or D to C, the work done is ..the same.. in each case.

When it is moved from B to C ..no work.. is done as BC is on an ..equipotential..

When it is moved around the path ABCD, the overall work done is ..zero..

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